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ASSESSMENT OF ORGANIC CARBON STOCK IN CASHEW PLANTATIONS (*Anacardium occidentale* L.) IN BENIN (WEST AFRICA).

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ABSTRACT

The present study aims to assess cashew plantations carbon sequestration potential following a climate gradient in Benin. The study was carried out in the Transitional, Sudano-Guinean and Sudanian zone, in the farmers' cashew plantations. The study was carried out from March to October 2016 and six plantations of 15 years and Diameter at Breast Height (DBH) between 0-20 and 20-40 cm were selected across the cashew growing areas. Allometric equations were used to assess carbon stock in the biomass and laboratory analyze to assess soil carbon stock. High carbon stock was recorded in the transitional zone (84.84± 4.06 t C /ha) against 63.14±3.78 t C /ha in the sudanian zone. In general, 78.9% of the carbon stock was found in the trunk of the trees against 19% and 2.1% respectively in the branches and in the leaves. Carbon sequestrated in the soil varied between 80.99 and 45.88% according to the zones. Temperature and the total carbon stock were significantly and negatively correlated (Pearson correlation coefficient r = -0.903 and P < 0.05). A rise of the temperature causes the decrease of the stock of carbon in the cashew plantations. Cashew-based cropping systems can be considered as carbon well.

Keywords: Allometric Equations, Benin, Climate Gradient, Cashew Tree, Carbon Sequestration.

1. INTRODUCTION

Recent progressive increase in temperature results from global warming caused by rapid increase of the greenhouse gases concentration in the atmosphere since the industrial era (Hahn *et al.*,

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2009). In early May 2013, the atmospheric concentration of carbon dioxide (CO_2) reached 400ppm (Ralph, 2013). In terms of carbon emissions, the African continent accounts for 17% of global emissions from changes in land use patterns and management patterns (Canadell *et al.*, 2009). Changes in land use patterns contribute to 48% to Africa's total carbon emissions. This level has probably not been achieved in the last 20 million years (IPCC, 2001) and continues to increase at a rate of about 2 ppm per year (Hansein, 2004). In general, tropical ecosystems are considered as sources rather than sinks of CO_2 since the savanna is grown and wood is harvested for energy and coal production (Tinlot, 2010). In this context, there is a need to better understand and quantify the dynamics of vegetation and carbon exchange regarding some climatic factors. In Benin, drought, late rains, violent and poorly distributed rains and floods are identified as three major climatic risks (Agossou *et al*., 2012). According to Ago *et al*. (2016), forest resources and ecosystems are essential to climate resilience as they help to conserve water resources, provide food, reduce the impact of natural disasters and provide the organic matter that improves soil fertility, carbon storage and farmers' livelihood. Carbon sequestration and an increase in soil organic matter will have a direct impact on soil quality. Agroforestry systems store carbon in tree biomass in the root and the aerial biomass (Peichl *et al.,* 2006). Indeed, the chlorophyll plants take photosynthesis of the CO_2 in the atmosphere that they assimilate for their maintenance, growth and energy needs. These ecosystems lose large quantities of carbon actually re-emitted into the atmosphere in the form of CO_2 through respiration and cashew plantations are not exception to this process (Tandjiékpon, 2010).

Cashew (*Anacardium occidentale* L.) plantations stand apart among other tree species because of their increasing importance in terms of areas and alternative to reforestation. It is among the world's top nut export crops with 7 million hectares of plantation (FAO, 2015). In Benin, cashew tree is an economic crop grown in small farms by more than 200,000 smallholder farmers on 485,000 ha of plantation (Weidinger and Tandjiékpon, 2014). Its production contributes to 3% to National Gross Domestic Product (GDP) and 7% to Agricultural GDP. The cashew-based agroforestry system in Benin solves three important and complementary development problems, namely economic, social and environmental (Tandjiékpon *et al.*, 2003). The cultivation of the cashew tree is therefore an economic activity that preserves and restores the environment. The use of cashew plantations is a sustainable solution for combating human pressure on tree species (Tandjiékpon *et al.,* 2003). According to Boillereau and Adam (2007), these plantations contributed to good carbon sequestration. The study of the carbon stock in terrestrial ecosystems in the context of climate change has been done on many forest species in many regions. In Cameroon for example, studies have revealed that tree-based systems such as cocoa agroforests, carbon sequestration are double than that observed in the traditional fallows. Thus, the conversion of one hectare of short-term cocoa-based agroforestry fallow could reach 72 tons of carbon (Durot, 2013). By extrapolation and because of its architecture, the cashew trees could have a similar or more impact on atmospheric carbon sequestration in savanna Africa (Tandjiékpon, 2005) including Benin.

Thus, the overall objective of the present study is to assess the organic carbon stock in the cashew plantations (*Anacardium occidentale* L.) in Benin, regarding the climate gradient. Specifically, it aims : i) to assess the stock of organic carbon stored in the trunks, branches and leaves of cashew nuts, and in the soil and litter of cashew plantations in the production areas of Benin; ii) to quantify the stock of total organic carbon stored in the cashew plantations and iii) to analyze the changes in the total organic carbon stored in the cashew nurseries according to Benin's climatic gradient. Knowledge gained from the present study will provide an insight into the contribution farmers' cashew plantations to the restoration of degraded areas and mitigation of the effects of climate change.

2. MATERIAL AND METHODS

2.1 Description of the study area

The study was carried out in six districts in Benin located in four agro-ecological zones (AEZ) favorable for cashew cultivation. The districts were selected according to the climatic gradient (South-North). The selected site include Djidja, Glazoué and Savè in the transitional AEZ (centre), Djougou in the Atacora AEZ (North West), Nikki in the south Borgou AEZ (North East) and Kandi in the northern Borgou AEZ (extreme North). Data were collected in the villages of Adourékoman in the district of Glazoué, Gobé in the districts of Savè, Dan in the district of Djidja, Serekali in the district of Nikki, Kassakou in the district of Kandi and Founga in the district of Djougou (Figure 1). The characteristic of these areas are presented in Table 1. The major soil types are ferric luvisols with fine clay-sandy texture.

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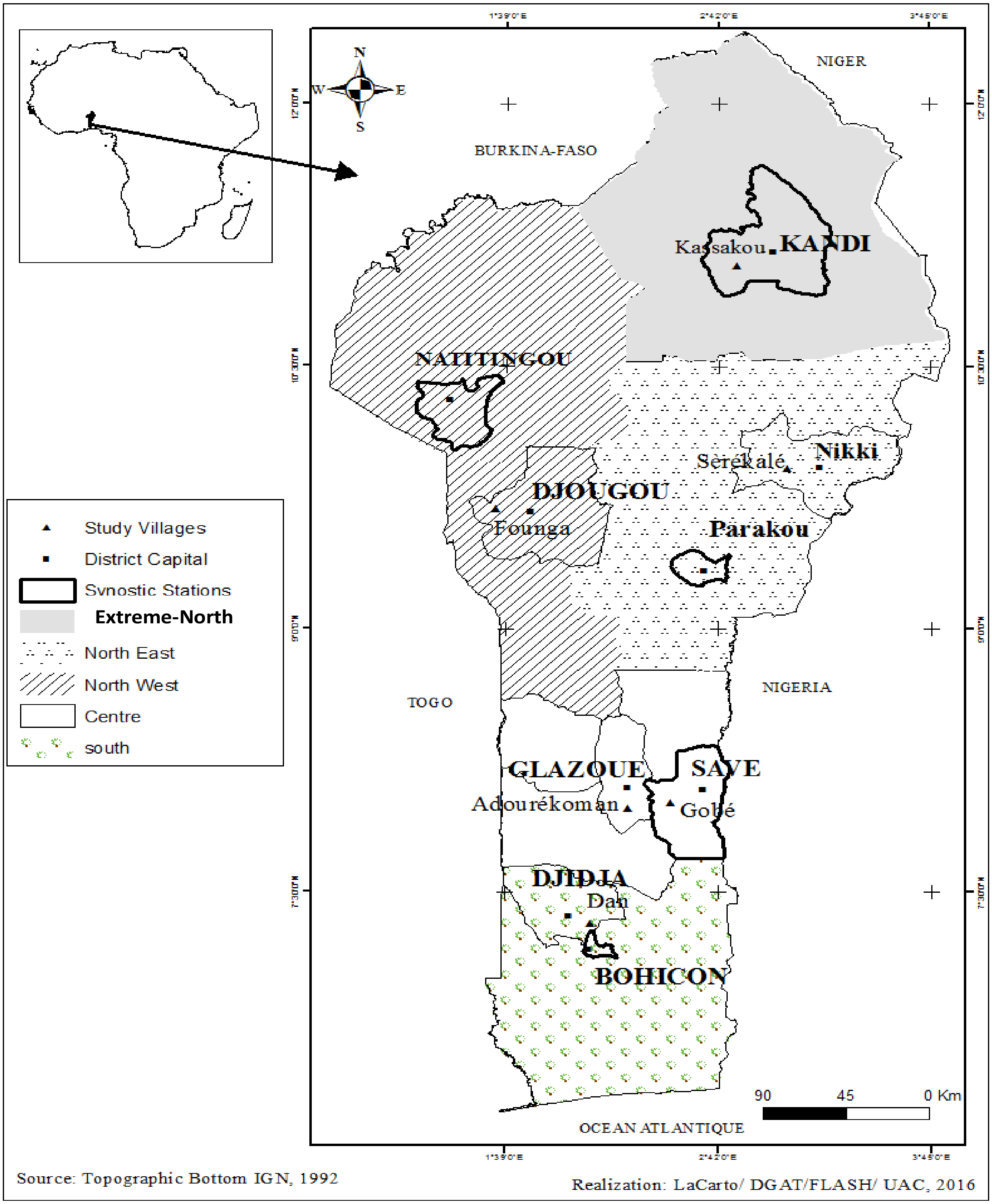

Figure 1: Map of Benin presenting the study areas

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Table 1: Characteristics of study area

Area	District	Production area	Season. Rainfall and Temperature (Gnanglè *et al.*, 2011; Bello *et al.*, 2016)	Climate	Apparent density (g/cm3)			Density (trees/ha)
					0-20 cm	20-40 cm	40-60 cm	
Centre	Glazoué	High favorable	-Two rainy seasons and two dry season Rainfall : 900 to 1100 mm Temperature : 21.2°C and 32.5°C	Transition	1.32	1.54	1.63	225
	Savè		Two rainy seasons and two dry season Rainfall : 959.56 to 1255.5mm Temperature : 24 and 29°C.		1.09	1.26	1.14	475
North west	Nikki	Medium favorable	One rainy season and one dry season Rainfall : 900 et 1200mm Temperature : 26 and 32°C	Sudanian	1.25	1.31	1.29	139
South	Djidja	Low favorable	Two rainy seasons and two dry seasons Rainfall : 1000 to 1200mm Temperature :26 and 31°C	Sudano-guinean	1.17	1.27	1.44	250
North west	Djougou	Medium favorable	One rainy season and one dry season Rainfall :1200 mm Temperature : 27.5°C	Sudano-guinean	1.34	1.49	1.49	200
Extreme -North	Kandi	Low favorable	One rainy season and one dry season Rainfall : 1100mm Temperature : 20°C and 36°C	Soudanien	1.42	1.49	1.59	100

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The basic biological material of this study consists of 15-year-old cashew (*Anacardium occidentale* L.) tree plantations retuned from the study conducted by Bello *et al*., (2017). The trees on which data were collected were identified base on an inventory (Balogoun *et al*., 2016). These cashew trees were chosen randomly in a delimited plot of 400 m² in each plantation to assess the trees' density. In each plot, three DBH (Diameter at Breast Height: 1.30 m from soil) trees between 0-20 cm and three DBH trees between 20-40 cm were selected per plantation as replication, in each district. A total of 36 Trees were selected.

2.2 Methods of data collection tools

The meteorologicals data (maximum and minimum temperatures (°C), and Rainfall (mm) were collected at the synoptic station of the Agency for Safety and Air Navigation in Africa and Madagascar (ASECNA) located at Bohicon (Southern zone); Savè (central zone); Natitingou (Northwest zone), Parakou (North-East zone) and Kandi (extrem north) (Bello *et al.*, 2016). These data were therefore collected over 15 years (2000-2015).

The biomass measurements were done on each plot of 400 m². The plots are rectangular, which is considered as more heterogeneous and more representative of the stand (Hairiah, *et al.*, 2011). The plot provides a representative view of the plantations in the form of a transect. Initially, the inventory of the cashew plantation was carried out and measurement of tree DBH to select cashew trees belonging to DBH classes between 0-20 cm and 20-40 cm, tree observations (architecture, size and yield) were done. The number of cashew trees per plot was recorded and used to compute the population density. The height of each tree was then measured using a SUUNTO clinometer.

The diameter at breast height (DBH) was determined from the circumference measured using a tape measure, 1.30 m above the ground. This DBH was calculated using the formula:

$$DBH=\frac{c}{\Pi}$$ with c : The circumference of the tree at 1.30 m above the ground.

The trees' height (H) was determined base on two sightings. A first at the top of the shaft (V1) and a second at the foot of the shaft (V2). These two sightings are in percentage of the distance (L) separating the operator from the tree. The total height of the measured tree is obtained using relation established by Rondeux (1999):

$$H=\frac{(V2-V1)*L}{\mathbf{100}}$$

The Soil bulk density was determined using the cylinder method. A sample of soil is taken using an hollow metal cylinder of 100 cm^3 volume. The clod extracted with the cylinder is then shaved at the end. The volume of soil removed is equal to that of the cylinder. The soil is then removed

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and dried in an oven at 105°C in the Soil Science Laboratory, Faculty of Agronomic Sciences of University of Abomey-Calavi and then weighed.

The methodology for estimating sequestered carbon is based on the recommendations of IPCC (2003) in the "Good Practice Guidance for Land Use, Land-use Change and Forestry" (LULUCF) as well as that proposed by MacDiken (1997), and the method described by Valentini (2007). It consisted in evaluating the biomass of the different parts of the tree (aerial and underground) and the determination of soil organic matter.

Soil carbon was determined through the estimation of the total organic carbon at different soil depths or globally for one or more horizons and the transformation of the data, taking into account soil bulk density. The stock of organic carbon was determined using Equation 1. The result was expressed as the total amount of carbon in ton C / ha at specified depths (FAO, 2002).

Equation (1)

$$SOC = \sum_{Depth=1}^{Depth=n} SOC_{Depth} = \sum_{Depth=1}^{Depth=n} ([SOC] * AD * P * (1 - frag) * 10)_{Depth} \quad (1)$$

With: SOC = organic carbon content in the soil samples (in ton C ha^{-1}); SOC_{depth} = soil organic carbon (ton C ha^{-1}) of the soil depth; [SOC] = Concentration of organic carbon in the soil obtained from the laboratory analysis (g C kg / soil); AD = Soil bulk density (ton of soil / m^3); P = sampling depth or thickness of the soil layer (m); frag = Percentage of the volume of coarse fragments / 100.

Under each selected tree, soil samples were collected at 0-20, 20-40 and 40-60 cm depth at three different points to form composite samples. A total of 126 soil samples were collected (6 trees x 3 depths and 3 sampling for the bulk density x 6 study areas). The soil samples were dried at room temperature and then sieved through 2 mm in order to separate the fine and coarse elements. These samples were used for the chemical analysis. The amount of carbon in the herbaceous vegetation and litter was done in three quadrats of 1 m² of surface area at each main plot and then used to compute the amount per hectare. All the vegetation present in each quadrat was cut and then the litter in each quadrat was collected and then weighed in situ. Then vegetation and litter samples were taken and send to the laboratory for chemical analysis. The chemical analyzes were carried out at the Laboratory of Soil, Water and Environment (LSSEE) of the National Institute of Agricultural Research of Benin (INRAB). Soil organic carbon was determined following Walkley & Black, (1934) method which consists to oxidize soil organic matter with potassium dichromate ($K_2Cr_2O_7$ 1N) in an acid medium in a sol / $K_2Cr_2O_7$ ratio of 0.25 / 10. The carbon content is determined by titration with 0.5 N iron sulphate solution after addition of diphenylamine indicator. For the assessment of carbon stock in the above and root

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biomass many authors recommended specific regression equations for the most encountered species for improving the reliability of the results (MacDiken, 1997; IPCC, 2003). Cashew was considered as large tree (height ≥ 7 m, these biomass were estimated following the equations 2 and 3 developed by FAO (1997) for arid zones (< 1500 mm per year). Equation 2 and 3 have been used for areal biomass and root biomass stock determination.

Equation (2): AB = $exp^{(-1,996+2,32 lnD)}$; With AB = Aerial Biomass, D = Diameter of the tree (D in cm)

Equation (3) = RB = $exp^{(-1,0587+0,8836*\ln(BA))}$ With RB = Root Biomass

The amount of carbon in the different tree's parts in each plantation was made on the basis of the allometric equations developed by FAO (1997) and adapted by Boulmane *et al.* (2013) according to the carbon stock models for the different components of the tree (Table 2).

Table 2: Allometric equations to assess carbon stocks in the various components of the trees

Component of the tree	Ajusted model of carbon stock Estimation (Kg/tree)	R^2
Trunk	SCTr = 191 x (D^2H)	0.97
Branches	SCBr = 46 x (D^2H)	0.95
Leaves	SCL = 5.4 x (D^2H)	0.96

Note: D = diameter at 1.30 m, H = height of the tree (in meter), D and H are in meter (m). SCTr = carbon stock in the trunk, SCBr = carbon stock in the branches, SCL = carbon stock in the leaves.

The litter and herbaceous plant samples were dried in an oven at 65 °C for 72 hours and then ground and the organic carbon was determined using dry ashing method. The percentage of dry matter of the herbaceous vegetation was determined from Equation 4 and the biomass using Equation 5 (Valentini, 2007). The average herbaceous biomass was then converted to ton per hectare.

Equation (4): DM = (PSE/PHE)*100 where DM = percentage of dry matter (%); PSE = dry weight of the sample after three days in the oven at 65 ° C (g); PHE = wet weight of the sample measured in the field (g).

Equation (5): B = (PHT*DM)/100; where: B = biomass (g); PHT = total wet weight in measured in the field (g); DM = percentage of dry matter (%).

2.3 Statistical analysis of data

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The Statistical Analysis System version 9.2 software (SAS v. 9.2) was used for the statistical analysis. Carbon stocks in the herbaceous biomass and litter were subjected to one-way ANOVA considering the study area. The C stocks in the above and root biomass as well as total C stock in the plantations were submitted to a two-way ANOVA considering the study area and the DBH. The C content and soil organic C stocks were subjected to three-way ANOVA considering the study area, the DBH and the depth. The Student Newman-Keuls test at the 5% threshold (probability level) were used for the means separation. Correlations between climatic factors and carbon stock were also done using the MINITAB 14 software. A simple linear regression model was established between the carbon stock and the mean temperature following equation y = f (x) where y = carbon stock and x, mean temperature (Nabikolo *et al.*, 2012). The mean standardized anomaly indices for each district were calculated as follow (Lamb, 1982):

$$IP = \frac{Xi - Xm}{\sigma} \quad (6)$$

With Xi (ton/ha) = Carbon stock for each district, Xm (ton/ha) = mean of the carbon stock in the study area, σ = standard deviation of carbon stock. Similarly, the carbon stock trend analysis were performed following method described by Bowerman and O'Connell (1993) regarding the climatic gradient Sudanian - transition -Sudano- Guinean zones. This trend was assessed taking into account regression equations and the determination coefficient R^2 (Rimi *et al.*, 2011).

3. RESULTS

3.1 Variation of rainfall and temperature regarding the climatic gradient

Figures 2 shows the trend of rainfall and temperature regarding the climatic gradient of respectively the Sudanian, transition –and the Sudano-Guinean zones. It is noticed that the rainfall has a rising trend according to the climatic gradient. During the last fifteen years, the Sudano Guinean zone has been rainier than the Sudanian zone. The temperature showed a regressive tendency according to the climatic gradient revealing a much warmer period in the Sudanian zone compared to the Sudano-Guinean zone.

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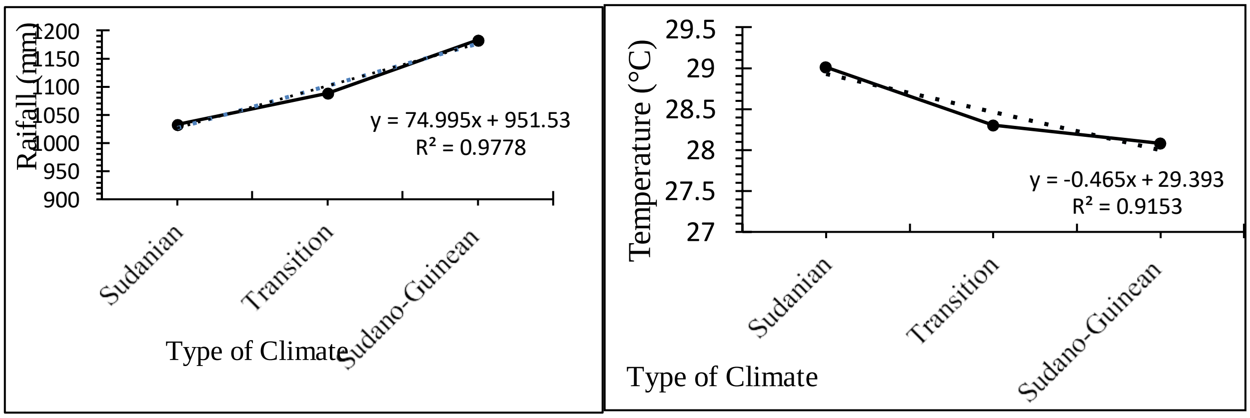

Figure 2: Rainfall and Temperature trend regarding to the climatic gradient.

3.2 Stock of organic carbon in the different compartments of cashew nuts

The results of the analysis of variance of the carbon stock in the trunk, branches, leaves, above and root biomass considering the study area and the DBH are presented in Table 3. The results of the organic carbon stocks in the various parts of cashew tree are presented in Table 4. In general, the study area and the DBH of the trees affected significantly ($P < 0.001$) the stock of Carbon in the trunk, branches, leaves, above and root biomass of the cashew trees. Furthermore, the interaction between the study area and the DBH has significant effect ($P < 0.05$) on the carbon stock in the trunk, branches, leaves, above and root biomass. It appear also from the Table 4 that the Upper North and the North-West in the sudanian zone, no significant differences were observed between the DBH classes with respect to the carbon stocks in the Trunk, branches, leaves, aerial and root biomass. In the Central zone, the same observation was made, but only at the trunk level, for the other parts of the tree, namely branches, leaves, aerial and root biomass, the highest stock value of carbon was obtained with the DBH classes 20 to 40 cm. In the South and North-East zones, the highest values of the carbon stock were also obtained with DBH classes 20-40 cm. In general, the highest carbon stock were observed in the Center and the South compared to the Upper North where the lowest carbon stock value was recorded. The carbon stock in the various parts of the tree is distributed as follows:

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Table 3: Result of the two ways ANOVA (F values) of the carbon stock in the above and root biomass regarding the DBH and geographical area.

Source of variation	Degree of freedom	Fisher's Value				
		SCTr	SCBr	SCL	SCAB	SCRB
Zone	4	8.88***	8.88***	8.88***	9.99***	10.8***
DBH	1	38.6***	38.6***	38.6***	37.20***	36.47***
Zone*DBH	4	3.10 *	3.10 *	3.10*	2.91 *	3.65 *

SCTr: carbon stock in the trunk; SCBr: carbon stock in leaves; SCL: carbon stock in leaves; SCAB: Carbon stock in aerial biomass, SCRB: Carbon stock in root biomass. DBH: Diameter at breast height, *: P< 0.05; **: P <0.01; ***: P <0.001

Table 4: Effect of the trees' DBH on the carbon stocks in the trunk, branches, leaves, the above and root biomass considering the climatic zones

Zones (Climate)	Trees' DBH (cm)	SCTr (t C/ha)	SCBr (t C/ha)	SCL (t C/ha)	SCAB(t C/ha)	SCRB (t C/ha)
	0-20	9.65 ± 1.47 a	2.32±0.35 b	0.27±0.04 b	13.6±2.01 b	2.66±0.34 b
Centre	20-40	26.05± 3.5 a	6.27± 0.84 a	0.74±0.1 a	33.24±4.35a	7.71±0.99 a
(Transition)	Mean	17.85 ± 3.06 A	4.3±0.74 A	0.5±0.09 A	23.42±3.74A	5.19±0.91 A
Extreme-	0-20	3.33±0.81 a	0.80± 0.19 a	0.09±0.02 a	4.6± 1.03 a	1.05± 0.15 a
North	20-40	4.99± 0.45 a	1.20 ±0.11 a	0.14 ±0.01a	6.66±0.55 a	1.64±0.1 a
(Sudanian)	Mean	4.16±0.56 C	1.00±0.13 C	0.12± 0.01C	5.63±0.69C	1.35 ±0.16 B
North East	0-20	3.29±0.32 b	0.79± 0.07 b	0.09±0.01 b	4.73± 0.41 b	1.26±0.07 b
(Sudanian)	20-40	11.17± 0.6 a	2.69±0.142 a	0.32±0.02 a	14.22±0.67a	3.03±0.33 a
	Mean	7.23 ±1.79 BC	1.74±0.43BC	0.2±0.05 BC	9.47±2.15 BC	2.15±0.43 B
North West	0-20	6.04±1.93 a	1.45±0.46 a	0.17±0.05 a	8.39±2.49 a	1.81±0.58 a
(Sudano-	20-40	18.67±5.44 a	4.5±1.31 a	0.53± 0.15 a	23.24±6.10 a	4.14±1.1 a
guinean)	Mean	12.36±3.82 AB	2.98±0.92 AB	0.35±0.11AB	15.81±4.44 AB	2.98±0.77B
South	0-20	7.38±2.08 b	1.78±0.5 b	0.21±0.06 b	10.32±2.62 b	2.26±0.53 b
(Sudano-	20-40	29.70±5.27 a	7.15±1.27a	0.83±0.15 a	36.26±5.82 a	6.78±0.79 a
guinean)	Mean	18.54±5.6 A	4.47±1.35 A	0.52±0.16 A	23.29±6.47 A	4.52±1.09 A

Means (mean values ± standard errors) followed by the same alphabetical letters of the same characters and for the same parameters are not significantly different (P> 0.05) according to Student Newman –Keuls test. SCTr = carbon stock in the trunk; SCBr = carbon stock in leaves; SCL = carbon stock in leaves; SCAB = Carbon stock in aerial biomass, SCRB = Carbon stock in root biomass, DBH = Diameter at breast height

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3.3 Stock of organic carbon in the litter and the herbaceous vegetation in plantations

The results of the analysis of variance of the carbon stock in the litter and the herbaceous biomass in the cashew plantations in the different zones showed significant difference ($P < 0.05$) between the study areas considering the stock of carbon in the litter. Table 5 presents the average values of the carbon stock in the herbaceous biomass and in the litter regarding the study areas. No significant difference ($P>0.05$) in the carbon stock in the herbaceous biomass was found. The Student Newman-Keuls test (Table 5) showed that cashew plantations in the Transition and Sudanian zone have significantly ($P < 0.01$) stored more carbon in the litter than Sudano-Guinean.

Table 5: Carbon stock in the herbaceous biomass and the litter of the cashew trees in four production zones

Zones (Climate)	Herbaceous Biomass (t C/ha)	Litter (t C/ha)
Centre (Transition)	3.91±0.15a	4.24± 0.08a
Extreme-North (Sudanian)	4.47±0.13a	4.26±0.35a
North-East (Sudanian)	4.06±0.30a	3.99±0.30a
North-West (Sudano-Guinean)	4.01±0.24a	3.21±0.39ab
South (Sudano-Guinean)	4.02±0.02a	2.58±0.34b
Prob	0.3346	0.0023

Means (mean values ± standard errors) followed by the same alphabetical letters of the same characters and for the same characteristics are not significantly different ($P> 0.05$) according to Student Newman –Keuls test.

3.4 Stock of soil organic carbon in cashew plantations

The results of the analysis of variance of the soil carbon and soil organic carbon stock in the cashew plantation regarding the sampling depths, the study area and the DBH (Table 6) showed an significant effect ($P <0.001$) of the study area and the sampling depths on the organic carbon stock and the carbon content. The DBH did not induce significant effect ($P > 0.05$) on the organic carbon stock and soil carbon content. The interaction between the study area and the DBH was significant ($P <0.05$ to $P <0.001$) on respectively soil carbon content and soil organic carbon stock. In the Table 7 the mean values of soil carbon content and soil organic carbon stocks per sampling depth considering the DBH classes of the trees and the sampling depth. Regardless of the study area and the DBH class, the highest soil carbon content and soil organic carbon stocks values were observed with the sampling depth of 0 - 20 cm. The sampling depth 40 - 60 cm presented the lowest soil carbon content and soil organic carbon stocks values. Considering the sampling depth, the climatic zones and DBH classes, no significant difference ($P > 0.05$) among the different classes of DBH for soil carbon content and soil organic carbon

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stocks was found in the site of Kandi in the sudanian zone (Table 7). In the transitional zone, no significant (P > 0.05) difference was registered among the different DBH for soil carbon content. However, the highest value of soil organic carbon stock was observed with the DBH class of 0 - 20 cm. In the North East (Sudanian zone), the DBH class of 0-20 cm had the highest soil carbon content and soil organic carbon stock values compared to the DBH class of 20-40 cm. In the northwest, the DBH class of 20-40 cm had the highest soil organic carbon and soil carbon content values compared to the DBH class of 0-20 cm. In the southern zone (Sudano-guinean zone), no significant difference (P> 0.05) was observed between the DBH class for both carbon contents and soil organic carbon stocks. The DBH class of 20 - 40 cm presented the highest value of soil organic carbon stock compared to the DBH class of 0 - 20 cm. Overall, the Central in the transitional zone and the North-East in the Sudanian zone presented the highest carbon content compared to the North-West zone. For the soil organic carbon stock, the North East zone showed the highest value compared to the southern zone. The stock of soil organic carbon determined in the cashew plantation decreases with the sampling depth. The 0-20 cm soil sampling depth represents more than 40% of the stock of soil total carbon stock.

Table 6: Result of the three way analysis of variance (F values) of the soil carbon content and the stock of carbon in the soil regarding the DBH of the trees, soil depth and study area.

Source of variation	Degree of freedom	F Value	
		Soil carbon content	Stock of organic carbon in the soil
Zones	4	10.79 ***	7.35***
DBH	1	0.76 ns	0.92 ns
Horizon	2	100.72 ***	86.46***
Repetition	2	0.08 ns	0.36 ns
Zone * DBH	4	3.55 *	3.93**
Zone * Horizon	8	0.75 ns	0.71ns
DBH * Horizon	2	1.35 ns	1.53ns
Zone * DBH * Horizon	8	0.28 ns	0.37ns

DBH: Diameter at breast height ; ns : P > 0.05 ; ** : P < 0.01 ; *** : P < 0.001

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Table 7: Effect of the DBH classes and the climatic zone on the soil carbon content and the stock of soil organic carbon regarding the sampling depths.

Zones (Climate)	DBH (cm)	Horizon (cm)	Carbon content in soil (t C/ha)	soil organic carbon stock (t C/ha)
Centre (Transition)	0-20	0-20	10.78±0.62a	23.67±1.79a
		20-40	7.78±0.84b	18.98±2.10a
		40-60	5.40±0.73c	11.48±1.74b
		Mean	7.99±0.67A	18.04±1.59A
	20-40	0-20	9.14±0.39a	18.43±1.15a
		20-40	7.47±0.35b	14.93±1.20b
		40-60	5.38±0.32c	9.99±0.72c
		Mean	7.33±0.42A	14.45±1.01B
	General Mean	7.66±0.39X	16.25±0.98Y	
Extreme-North (Sudanian)	0-20	0-20	9.18±0.53a	23.59±1.11a
		20-40	6.94±0.43b	17.22±1.62b
		40-60	4.81±0.86c	10.51±0.61c
		Mean	6.98±0.70A	17.10±1.98A
	20-40	0-20	7.02±1.51a	18.41±3.61a
		20-40	5.78±1.15 ab	14.95±3.65ab
		40-60	3.60±0.21b	10.12±0.75b
		Mean	5.47±0.74A	14.49±1.92A
	General Mean	6.22±0.53YZ	15.80±1.37Y	
North-East (Sudanian)	0-20	0-20	11.67±0.59a	27.98±1.20a
		20-40	8.35±0.27b	20.34±0.74b
		40-60	5.42±0.24c	12.70±0.42c
		Mean	8.48±0.92A	20.34±2.24A
	20-40	0-20	10.44±0.43a	25.19±0.94a
		20-40	7.15±0.22b	17.92±0.56b
		40-60	4.65±0.15c	11.07±0.37c
		Mean	7.41±0.85 B	18.06±2.06B
	General Mean	7.95±0.62X	19.20±1.50X	
North-West (Sudano-Guinean)	0-20	0-20	7.79±1.77a	19.59±4.82a
		20-40	3.73±0.74b	10.41±2.67b
		40-60	3.22±0.42b	8.91±1.36b
		Mean	4.91±0.91B	12.97±2.30B
	20-40	0-20	8.85±1.21a	21.81±2.91a
		20-40	6.04±1.11ab	16.56±3.00ab
		40-60	3.83±0.16b	10.47±0.54b
		Mean	6.24±0.87A	16.28±2.04A
	General Mean	5.58±0.63Z	14.62±1.55 XY	
South	0-20	0-20	9.24±0.58a	19.13±1.32a

(Sudano-Guinean)		20-40	5.70±0.32b	11.35±1.07b
		40-60	3.79±0.18c	6.23±1.47c
		Mean	6.24±0.82A	12.23±1.98B
	20-40	0-20	8.83±0.66a	18.14±0.92a
		20-40	6.80±0.82b	13.36±0.70b
		40-60	5.21±0.36c	10.54±1.08b
		Mean	6.95±0.61A	14.01±1.20A
	General Mean	6.60±0.51Y	13.12±1.14 Z	

The means (mean values ± standard error) followed by the same alphabetical letters of the same characters and for the same parameters are not significantly different (P> 0.05) according to the Student Newman -Keuls test. DBH: Diameter at Breast Height.

3.5 Stock of carbon in the soil and total carbon stock in the cashew plantations

The results of the analysis of variance of the stock of organic carbon in the soil of the cashew plantations regarding the study area and trees' DBH are presented in Table 8. The total stock of carbon in the soil and that of the plantations are significantly ($P < 0.05$) affected by the study area. The trees' DBH classes did not significantly ($P > 0.05$) affect the total stock of carbon in the soil but it influences significantly ($P <0.05$) the total stock of carbon in the cashew plantations (Table 8). Table 9 shows the mean values of the total stock of carbon in the soil and in the biomass of cashew plantations regarding the DBH classes and the climatic zones. The DBH class of 20 to 40 cm showed the highest stock of carbon in the cashew plantations. In the North-East zone, the DBH class trees ranging between 20 and 40 cm showed the highest total stock of carbon in the cashew plantations, whereas trees of DBH class between 0 and 20 cm presented the highest stock of soil organic carbon. Overall, the North-East Zone showed the highest value of total stock of carbon in the soil while the highest value of the total stock of carbon in the cashew plantations was recorded in the Central zone.

Table 8: Two ways analysis of variance (F values) of the stock of organic carbon in the soil and the cashew plantation regarding the DBH and the study area. In bracket: P value

Source of variation	Degree of freedom	F Values	
		Total stock of carbon in the soil	Total stock of carbon in the cashew plantations
Zones	4	3.32*	3.29*
DBH	1	0.33 ns	11.38**
Zone* DBH	4	1.88 ns	2.64 ns

ns : P > 0.05 ; ** : P < 0.01 ; *** : P < 0.001 ; DBH: Diameter at breast height

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Table 9: Effect of the trees' DBH classes on the total stock of carbon in the soil and cashew plantations regarding to study area.

Zones (Climate)	Trees' DBH (cm)	Stock of carbon in the soil (t C/ha)	Total stock of carbon in the cashew plantations (t C/ha)
Centre (Transition)	0-20	54.13±5.32 a	78.54 ±4.32 a
	20-40	43.36±2.97 a	91.14±6.17 a
	Mean	48.75±3.33 AB	84.84± 4.06 A
Extreme-North (Sudanian)	0-20	51.32±2.62 a	65.87±3.57 a
	20-40	43.48±7.54 a	60.40 ±7.14 a
	Mean	47.40±3.98 AB	63.14±3.78 B
North-East (Sudanian)	0-20	61.02±0.76 a	75.34 ± 0.3 b
	20-40	54.18±0.69 b	79.24±1.29 a
	Mean	57.60±1.6 A	77.29 ±1.05AB
North-West (Sudano-guinean)	0-20	37.99±8.52 a	55.15±10. 6 a
	20-40	46.83±5.60 a	83.83 ±12.88 a
	Mean	43.41±5.17 B	69.49± 9.84 B
South (Sudano-guinean)	0-20	36.71± 2.84 a	55.73±5.96 b
	20-40	42.17±1.77 a	91.90± 8.20 a
	Mean	39.44±1.93 B	73.82±9.27 AB

The means (mean values ± standard error) followed by the same alphabetical letters of the same characters and for the same characteristics are not significantly different (P> 0.05) regarding the Student Newman -Keuls test. DBH: Diameter at Breast Height.

3.6 Trend and variability of carbon stock regarding the cashew growing area studied and the climate gradient

The variability and the trend of the stock of carbon along the cashew growing area are presented in Figure 4. There was a downward trend of the stock of carbon regarding the cashew growing area. However, the trends were less linear and did not have defined pattern regarding coefficient of determination (R^2) which presented low values. The best values of total C stock and the C stock of DBH 20-40 trees have been obtained in Savè district while the highest value of C stock of DBH 0-20 cm tree has been obtained in Glazoué distcrict. However, Kandi district has recorded the lowest value of total C stock and C stock of DBH 20-40 cm trees while Djougou and Djidja have obtained the lowest value of C stock of DBH 0-20 cm (Figure 3).

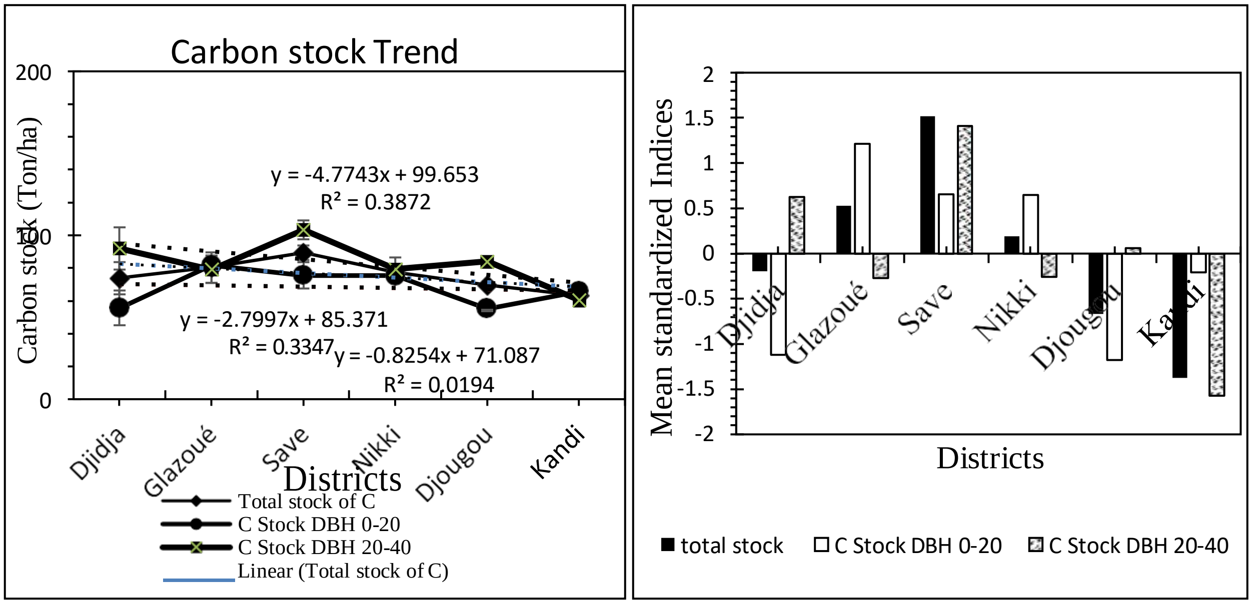

Figure 3: Trend and variability of the carbon stock along the cashew growing area studied

The analysis of the variation of carbon stock regarding the climatic gradient is presented in Figure 4. The stock of the total carbon level showed an increasing trend regarding the gradient, Sudanian - transition and Sudano-Guinean zones. This trend was less linear and did not have defined pattern regarding the coefficients of determination R^2 which are low. The highest carbon stocks considering the trees' DBH were obtained in the transitional zone (Figure 4).

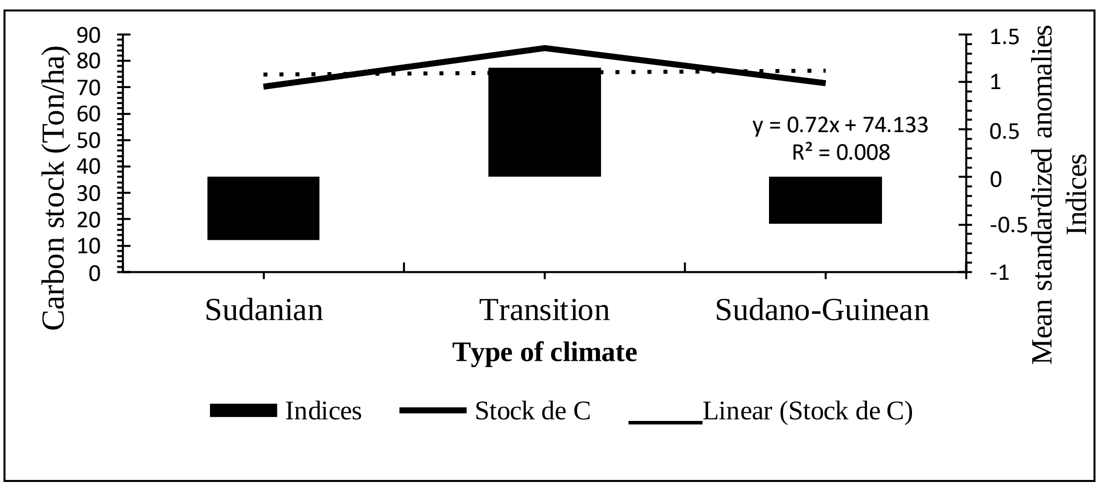

Figure 4: Carbone stock variability and trend regarding the climatic gradient

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3.7 correlation between carbon stock and climate parameters

The temperature and the rainfall averages over the past 15 years have been linked to the total organic carbon stock data obtained from the cashew plantations of the different study areas. From these results, there was a negative and significant correlation ($r = -0.903$; $P < 0.05$) between the stock of total carbon and the temperature. However, there is no correlation between the stock of organic carbon and the mean of the rainfall over the last 15 years ($r = 0.047$, $P > 0.05$). Thus, a model $y = 2.58T$, $P < 0.001$ were y = stock of total carbon and T = mean temperature, has been established between the average temperature and the total stock of carbon.

4. DISCUSSION

4.1 Carbon sequestration in cashew plantations in Benin

In the cashew production areas, the stock of carbon in the different compartment varies across locations and the DBH of the trees. Of course, trees with high DBH have stored more carbon. This finding substantiates previous result of Thompson *et al.* (2004) who have reported that the longer the tree grows, the more it sequesters carbon. The carbon stock is significantly higher in the aboveground biomass than the root. These results are in line with those of Montagnini and Nair (2004), who have shown that, carbon capture efforts in the tropical environments are concentrated on above-ground biomass rather than in the soils because in 25 years carbon stock in the above-ground biomass can increase by 50 t C / ha, compared to only 5 to 15 t C / ha in the soils. The carbon stock in the above-ground biomass varies between 5.63 ± 0.69 t C / ha and 23.42 ± 3.74 t C/ha, depending on the location. These results are close to those obtained by Albrecht and Kandji (2003) between 7 and 25 t C / ha in an agroforestry system. Nonetheless, these values are much lower than the range, between 40 and 60 t C / ha, given by Tinlot (2010) and Saïdou *et al.* (2012). in Bembérékè (24. 42 ± 6.98 t C / ha). The stock of carbon in the underground biomass varied between 1.35 ± 0.16 and 5.19 ± 0.91 t C / h. Only the C stocks values obtained in the northwest, centre and south are closed to 3 to 13 t C / ha obtained by Valentini (2007). However, the stock calculated is lower than those found by Oelbermann *et al.* (2004) (8 t C / ha) for the shea butter park in Mali. Depending on the location, soil organic carbon stocks vary between 13.12 ± 1.14 t C/ha and 19.20 ± 1.50 t C/ha. Which are included in the range of 11 to 33 t C/ha calculated by Volkoff *et al.* (1999) in Benin. These changes in the stock of soil carbon are a function of soil type and climatic conditions. The stocks of soil carbon are lower than those estimated by the IPCC, (2003) 31 t C/ha for the dry tropics and 42 t C/ha obtained by Tinlot, (2010) and Sonwa, (2004) in an agroforestry system based on cocoa. The low carbon content of the soil in cashew plantations could be explained by the higher decomposition of the organic matter linked to the higher temperatures observed in the study area. In addition, these soils are subjected to intensive cultivation practices with very short fallow period. The

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carbon stock in the organic matter in our study varied between 2.58 ± 0.34 t C/ha and 4.26 ± 0.35 t C/ha. This result is similar to 2.8 t C/ha determined by the IPCC, (2003). The high rate of carbon could be explained by the quality of the litter. The total carbon stock in the cashew plantations ranges from 63.14 ± 3.78 t C/ha to 84.84 ± 4.06 t C/ha. Similar research conducted by Rupa *et al.* (2013) in India showed that 7-year-old cashew plantations of between 156 and 600 trees per hectare stored between 32.25 and 59.22 t CO_2 / ha. According to Albrecht and Kandji, (2003), the carbon storage capacity of an agroforestry system varies between 12 and 228 t C/ha with an average value of 95 t C/ha. The values calculated in our study are included in this range. The change in C stock in the different zones could therefore be due to variation in the planting density. In fact, in the Central zone, there were approximately 475 trees/ha while at Kandi 100 trees per hectare were recorded. The fact that there was no difference ($P > 0.05$) between the southern and north-eastern zone regarding the C stock was due to the intensive development of the canopy (in the southern zone) due to the two Rainfall seasons characterizing the area. The amount of carbon sequestered by the agroforestry system depends on the tree species, plantation density, the structure and function of the latter. Montagnini and Nair, (2004) reported that the amount of carbon sequestered depends on tree species, geographic regions (climate, soil), planting densities and system management. The results obtained are, less than 60 and 90 t C/ha for a 20-year agroforest obtained by Lawal *et al.* (2010). The carbon stock in the soil of the plantation exceeds the estimated value for the agricultural system. This makes it possible to assert that the agroforestry system is a carbon sink in relation to an agricultural system. Thus, the carbon stock in natural forests is higher than that of the agroforestry system because regeneration is rapid and litter is abundant. Montagnini and Nair, (2004), noticed also that, agroforestry systems have an indirect effect on carbon capture by reducing pressure on natural forests.

4.2 Influence of climatic factors on carbon stock in the cashew plantations

The Rainfall, temperature and wind are the most important climatic parameters of agricultural production (Yabi *et al.*, 2013). According to Benin's 2nd National Communication on Climate Change, the agricultural sector, which plays a central role in Benin's economic and social development, is the most vulnerable sector to high climate variability and extreme climatic events. The present study reveals an increase trend in rainfall between 2000 and 2015 following the Sudanian, the Sudano - Guinean climatic gradient. In the Sudano-Guinean zone, the amount of rainfall was higher compared to the Sudanian zone. This decrease in the Sudanain zone shows that, the decrease in precipitation found in West Africa in general is also evident at the scale of this zone (Badjana *et al.*, 2014). However, in the Sudano-Guinean zone there is an upward trend in rainfall. The concentration of the most important precipitation values in this area can be explained by the influence of the topography. From the effect of climatic factors on the carbon

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stock, it is noted that the temperature has a negative and significant correlation with the carbon stock in the cashew plantations. As a result, a large amount of sequestered carbon in the study areas induced a reduction in atmospheric CO_2 emission thus attenuating the temperature. This result is consistent with the work of Reichstein (2007) and Jayathilaka *et al.* (2012) explaining that, high temperature induced a high CO_2 content, contributing to low carbon sequestration. The storage or release of carbon depends on both the processes of degradation of organic matter and the behavior of biomass in the face of climate change. The high temperature induces a high activity of the microorganisms (Fissore *et al.*, 2008), causing an oxidation of the organic matter that affects the CO_2 of the atmosphere. The increase in CO_2, stimulates photosynthesis and improves water efficiency (stomata would open less to assimilate the same amount of carbon) leading to increase of net primary production, both aerial and root. The contribution of carbon to the soil would increase (Reichstein, 2007). Furthermore, high rainfall leads to high primary productivity contributing to high CO_2 emissions (Reichstein, 2007). In general, the stimulation of plant productivity with higher temperatures will increase carbon in litter and soil (Reichstein, 2007); which has an impact on the environment due to a greater release of CO_2 into the atmosphere (Lawal *et al.*, 2010). The combined effect of rising temperatures and changing precipitation can increase water deficit. Litter decomposition would then be reduced and slowed down, leading to significant carbon storage in forest soils (Kurz-Besson *et al.*, 2006). The analysis of the carbon stock variation according to the climatic gradient revealed that the cashew trees in the transitional zone have sequestered significant amount of carbon. This result could be explained by the fact that the temperature of this zone has favored canopy growth which can capture CO_2 in the atmosphere and also, slow the mineralization of organic matter for carbon storage in soils. The low carbon stock obtained in the Sudanian zone could be associated with the observed high temperatures. According to Jayathilaka *et al.* (2012), the increase in temperature leads to a release of carbon from the soil.

CONCLUSION

The present study showed that cashew plantations constitute agroforestry systems that store varying amounts of carbon depending on the growing area. This variability is influenced by climatic factors. Considering the study areas, the highest amount of carbon is observed in the centre (transitional zone) while the lowest amount has been obtained in Kandi (sudanian zone) district. The temperature influences the amount of carbon sequestered in the cashew plantation. According to the different compartments to be considered in the plantation, the soil and the aboveground biomass stored high amounts of carbon. However, herbaceous biomass stock low carbon but it plays a considerable role in the soil sequestration potential. Given the results obtained, cashew producers could benefit from the global carbon market, which would increase their financial income. Therefore, policies must be designed to develop sustainable agrarian systems through the implementation of carbon sequestration projects related to climate change on cashew. In perspective, consideration should be given to undertaking studies on the emission of greenhouse gases (GHGs) on plantations to make a comparison between emission and sequestration.

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